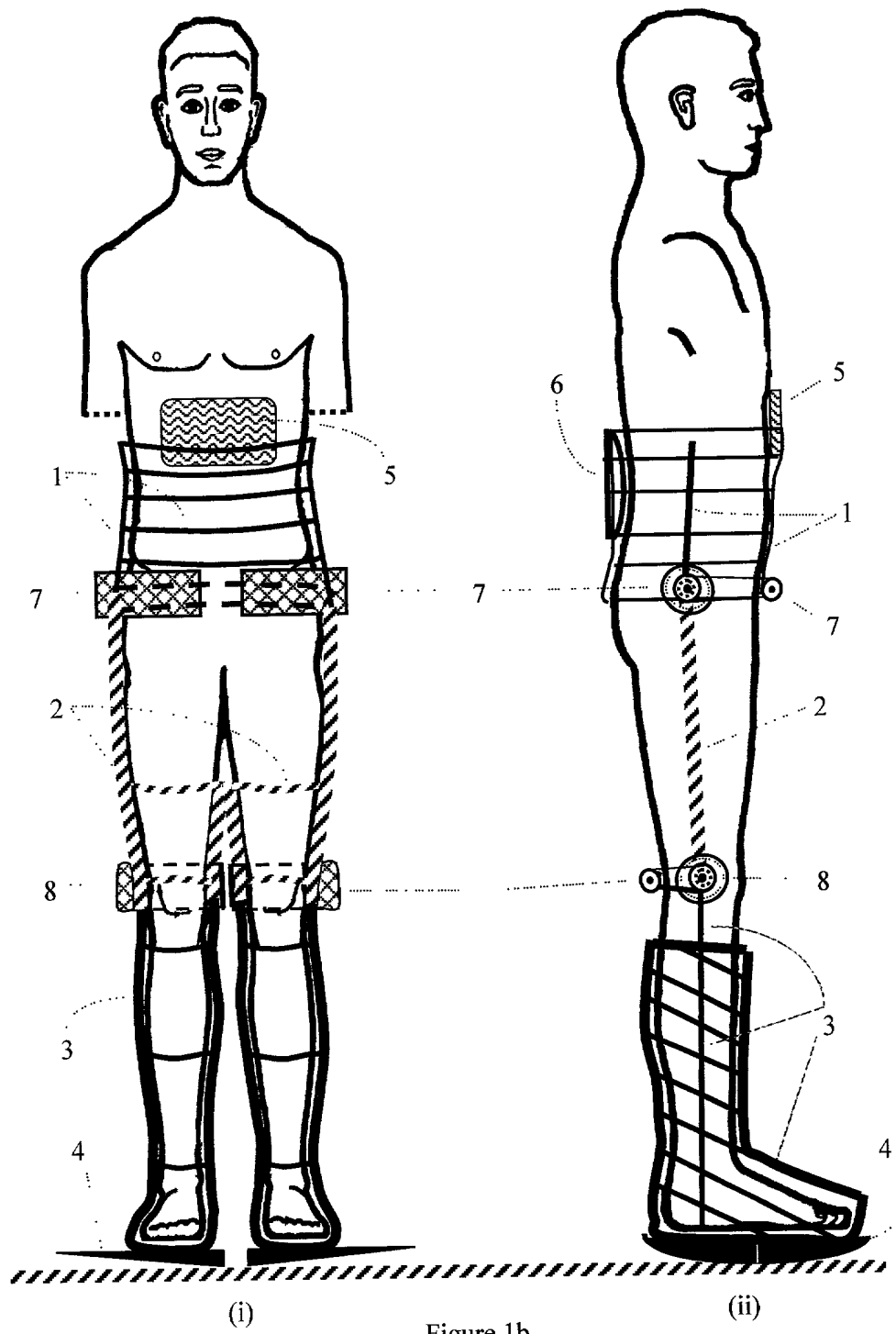Figure 1a

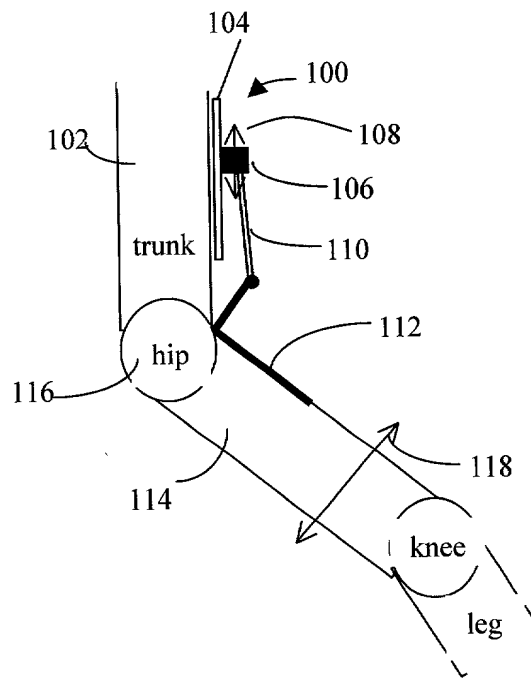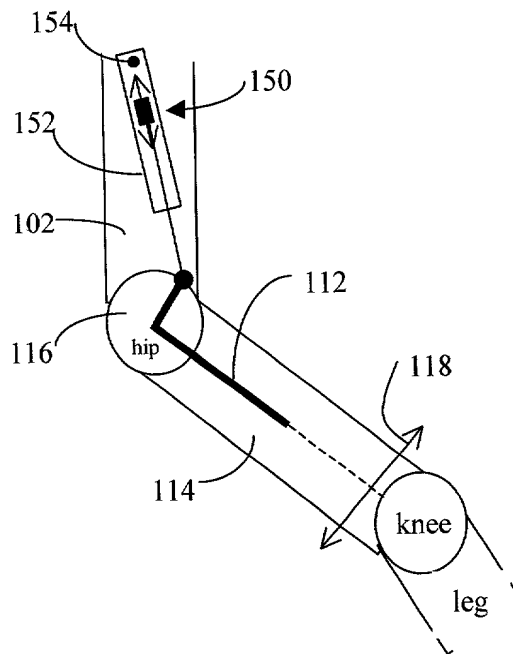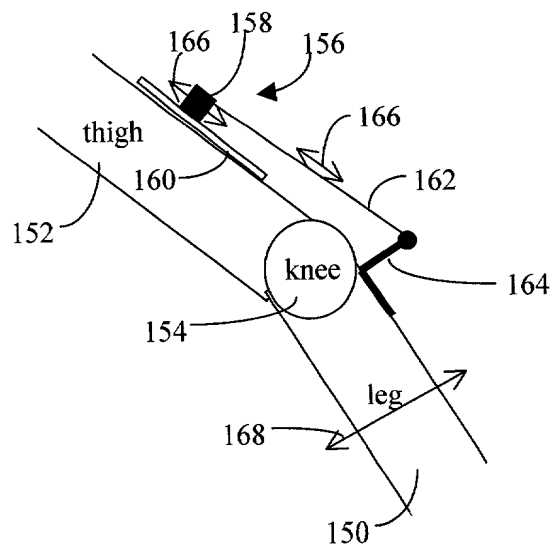analog signal ⟹ analog/power ➡ digital bus ⟹

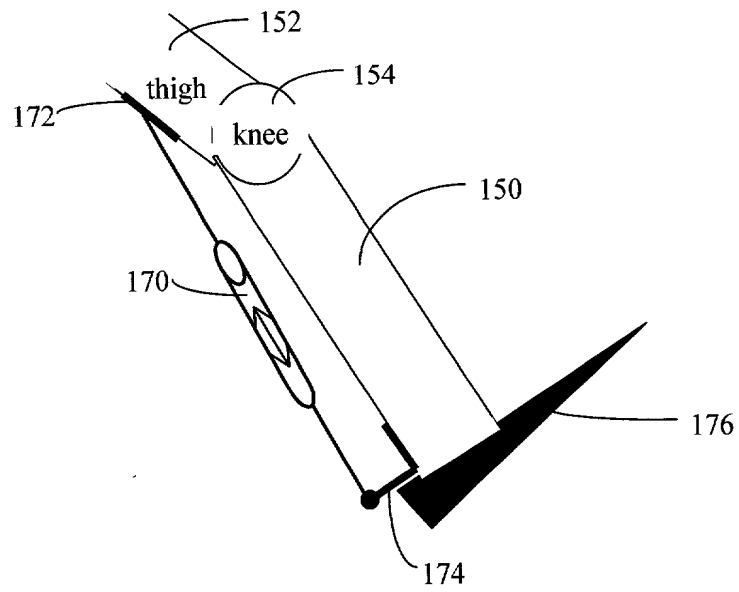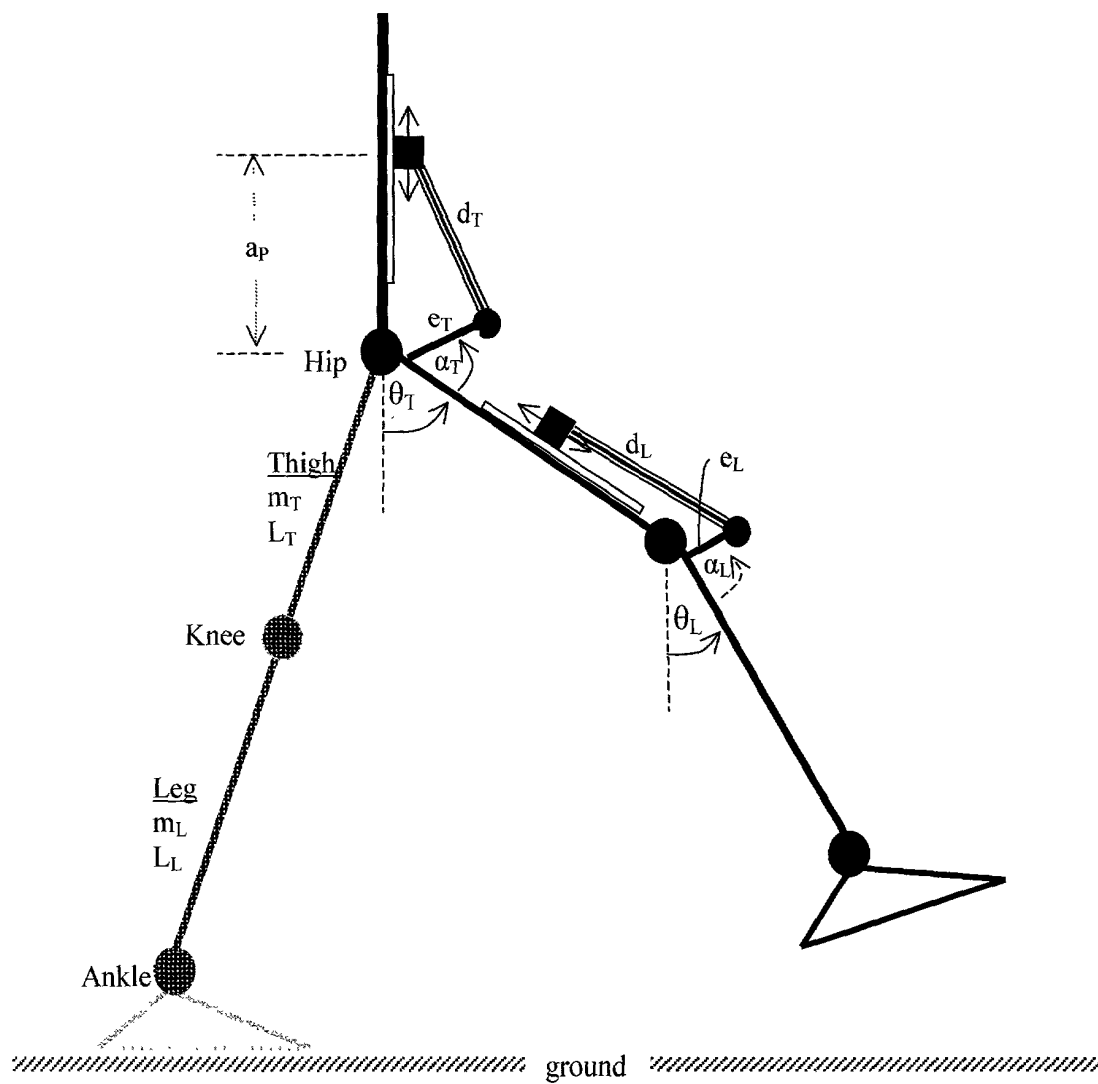(i)   (ii)

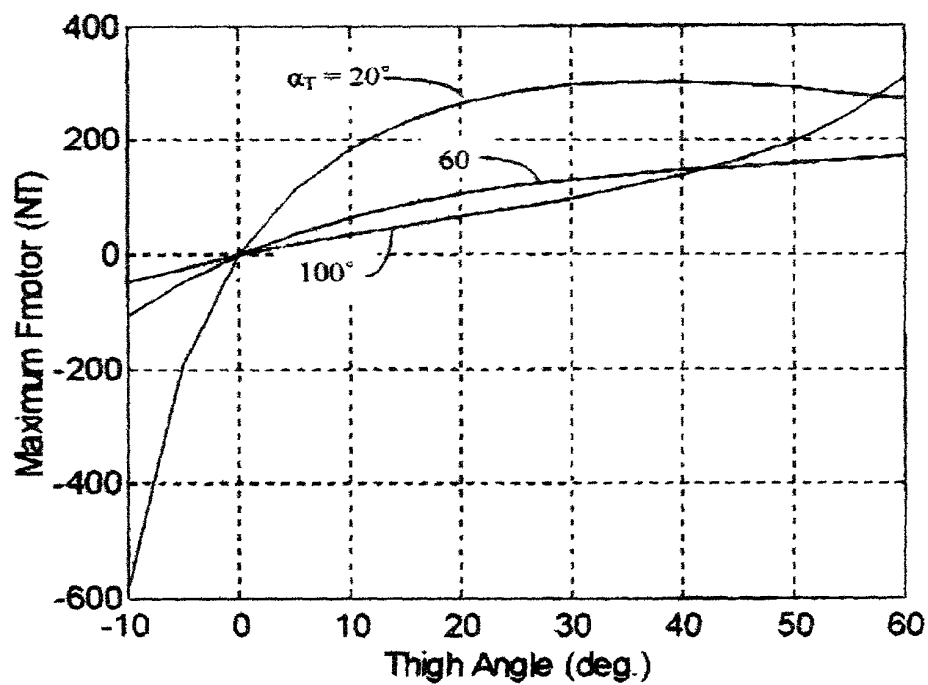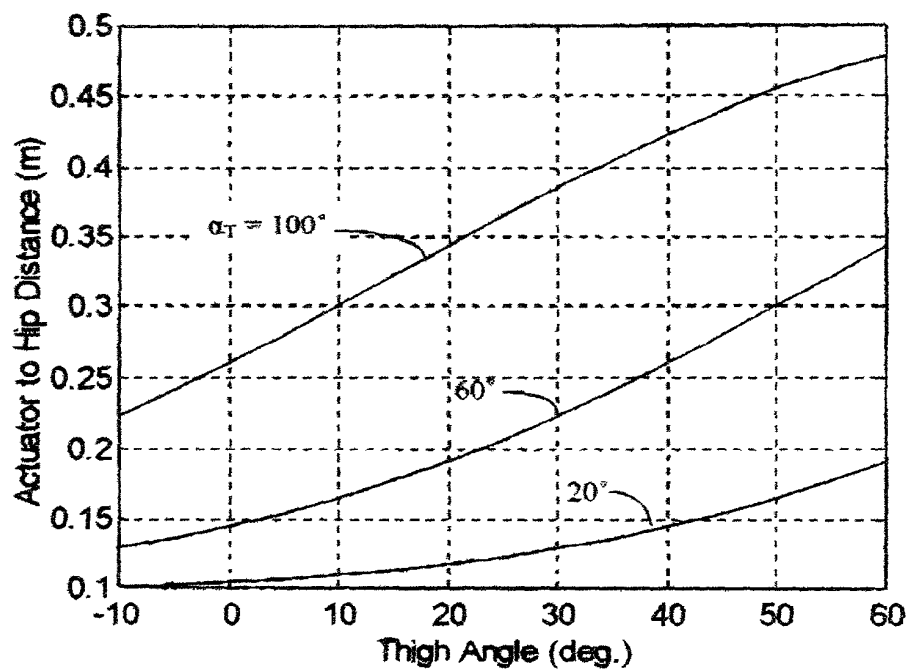Figure 1b

Figure 2a

Figure 2b

Figure 3a

Figure 3b

Figure 4

Figure 5a

Figure 5b

Figure 6

Figure 7a

Figure 7b
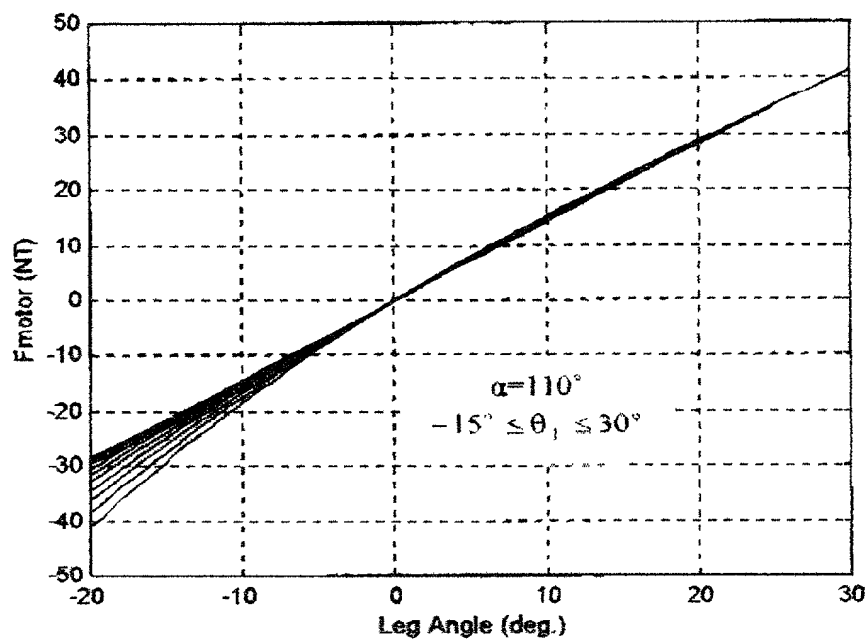
Figure 8
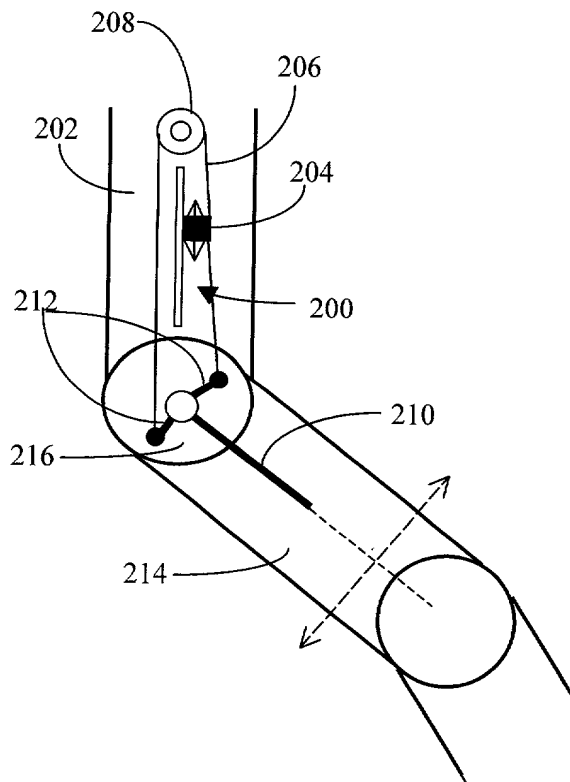
Figure 9a

Figure 9b

Figure 9c

Figure 10

Figure 11a

Figure 11b

Figure 12

Modes
stance
gait
lie-sit-stance
climb
descent
trainer
test
learn/adapt

mode cmd

Pattern Bank
stance pattern
gait pattern
⋮
$\{\,\theta_X = \theta_X(n,P)\,\}$
$X \triangleq \{RT,LT,RL,LL\}$

pattern set
$\Theta_p = \Theta_p(n)$

desired response
Θ_d

Logic Engine

cmd

feedback Θ
Θ_f

Controlled Environment

RT: right thigh

LT: left thigh

RL: right leg

LL: left leg

$\Theta_p \triangleq (\theta_{RT}, \theta_{LT}, \theta_{RL}, \theta_{LL})_{pattern}$

$\Theta_d \triangleq (\theta_{tilt}, \dot{\theta}_{tilt}, \ddot{\theta}_{tilt})_{desired}$

$\Theta_f \triangleq (\theta_{tilt}, \dot{\theta}_{tilt}, \ddot{\theta}_{tilt})_{feedback}$

$\Theta \triangleq (\theta_{RT}, \theta_{LT}, \theta_{RL}, \theta_{LL})_{actual}$

550

┌───┐
│   Stance: │
│ $\Theta_f \hat{=} (\theta_{tilt}, \dot{\theta}_{tilt}, \ddot{\theta}_{tilt}) \approx (0,0,0)$ │
│ $(\theta_{RT}, \theta_{LT}, \theta_{RL}, \theta_{LL}) \approx (0,0,0,0)$ │
└───┘

Legend
LK – left knee
RK – right knee
LF – left foot
RF – right foot
LL – left limb
RL – right limb
fwd – forward
bkw – backward
COM – center of mass
θ_{RT} – right θ_T
θ_{LT} – left θ_T
θ_{RL} – right θ_L
θ_{LL} – left θ_L

┌─────────────────────────────────┐
│ Tilt upper-body: $\|\Theta_{fl}\|\uparrow$ │   552
└─────────────────────────────────┘

┌─────────────────────────────────┐
│   Compute step parameters   │   554
│   using: $\Theta_p(n)$ & Θ_f │
└─────────────────────────────────┘

┌──┐
│ Form an RL/LL fwd step & lock LK/RK: │
│ RL/LL: $\Theta \rightarrow \Theta_p$ │
│ LL/RL is bkw: $\theta_L = \theta_T \sim -10°$ L/R   R/L │
└──┘

┌──┐
│   Place RF/LF on ground: │
│   COM moves fwd   │   556
│   Body weight is on both LL & RL   │
└──┘

┌──────────────────────────┐   ┌──────────────────────────┐
│   Straighten up   │   │   Fold LL/RL: │
│   & lock RK/LK   │   │ LL/RL: $\Theta \rightarrow \Theta_p$ │
│ $\theta_{tilt} \rightarrow 0°$ │   │   │
│ $\theta_{RL/LL} = \theta_{RT/LT} : \sim 20° \rightarrow 0°$ │   │   │
└──────────────────────────┘   └──────────────────────────┘

Turn
Command ⟶ ┌──────────────────────────┐
          │ Body weight   │   558
          │ is on RL/LL   │
          │ $\Theta_f \approx (0,0,0)$ L/R   R/L │
          └──────────────────────────┘

                                                560
              ◇───────────────────────◇
         Yes │   Switch Limbs   │ No
              │   ?   │
              ◇───────────────────────◇

Figure 13

602

604

606

608

Lie position:
$\theta_T=\theta_L=0°$

Sit position:
$\theta_T=\theta_L\to90°$
(strait feet)

Move to bed
edge and fold
knees
$\theta_T=90°$, $\theta_L\to0°$

Stance:
θ_T: $90°\to0°$

support
(if needed)

600

Figure 14

700

716

702

710

704

710

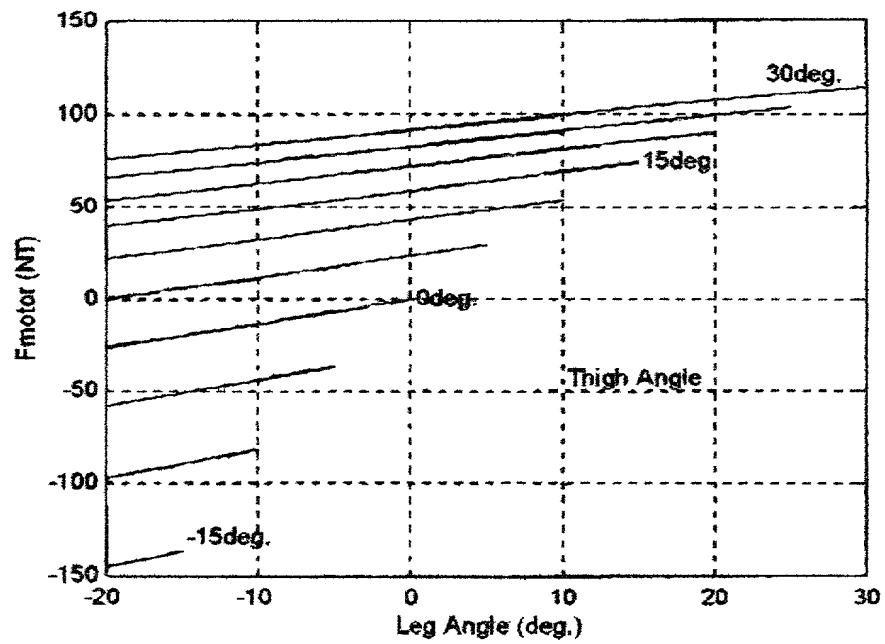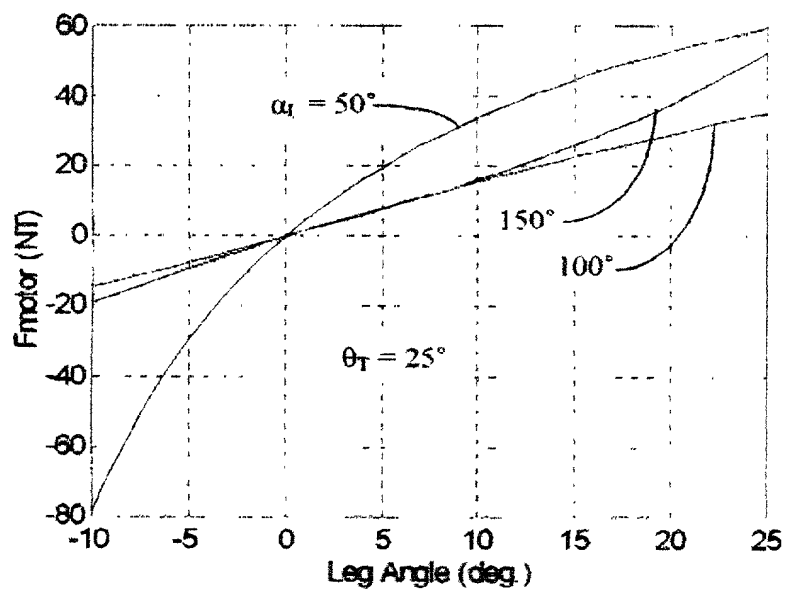706   706

712

714

708   708
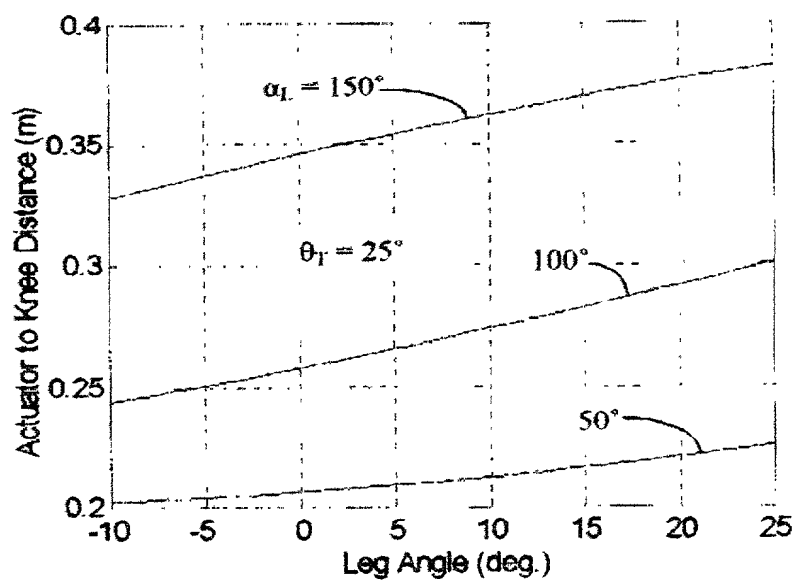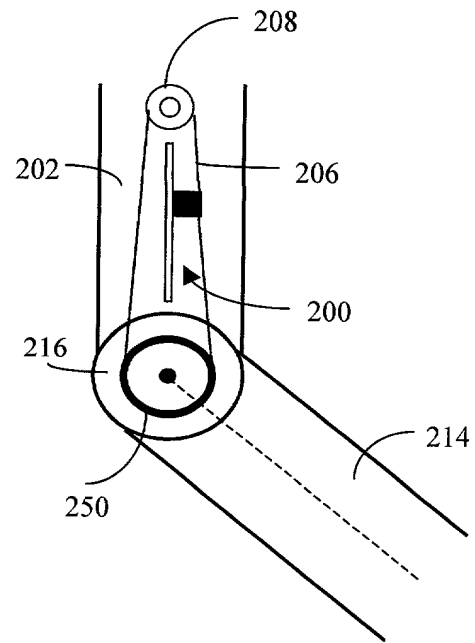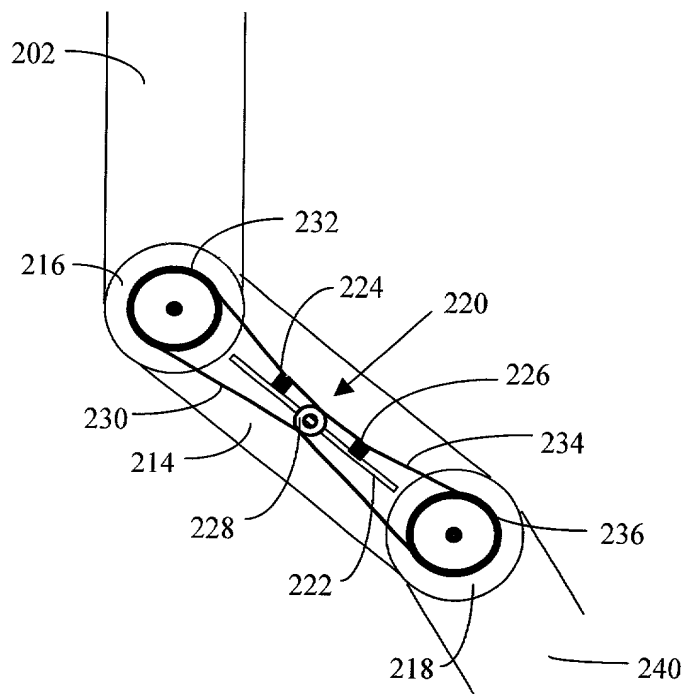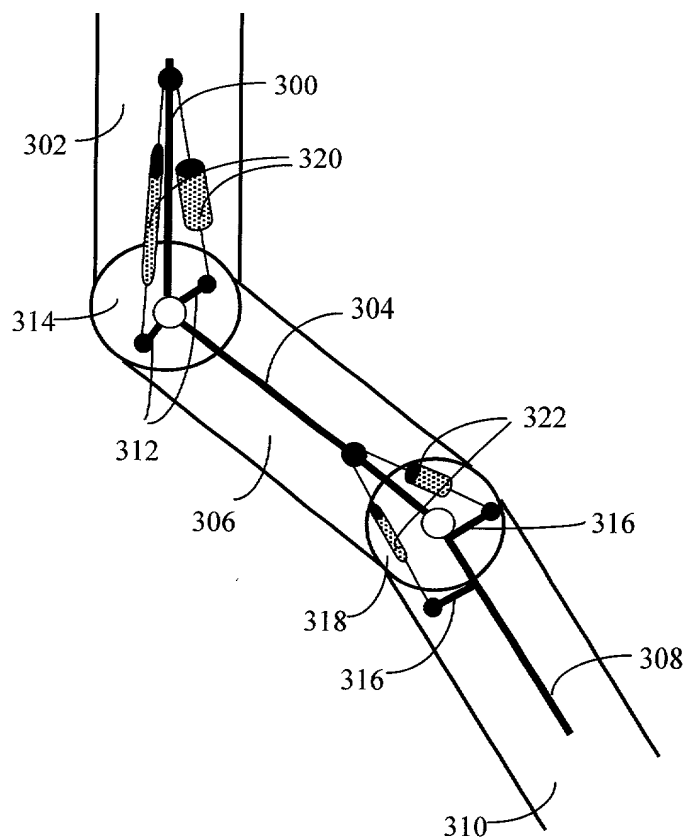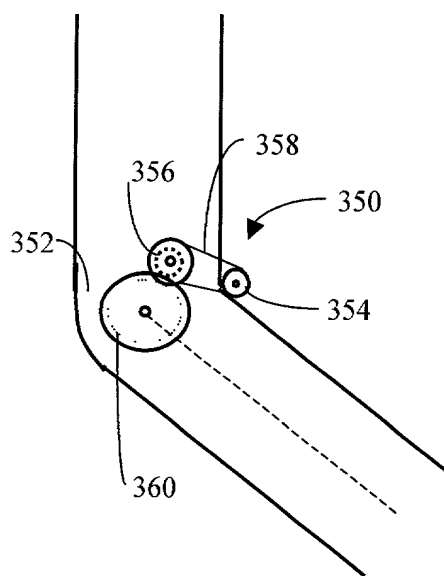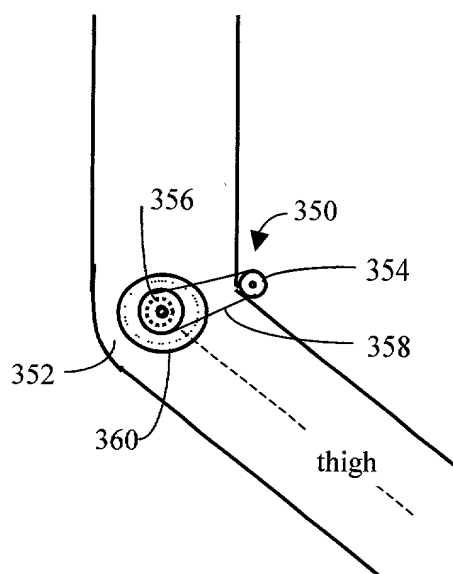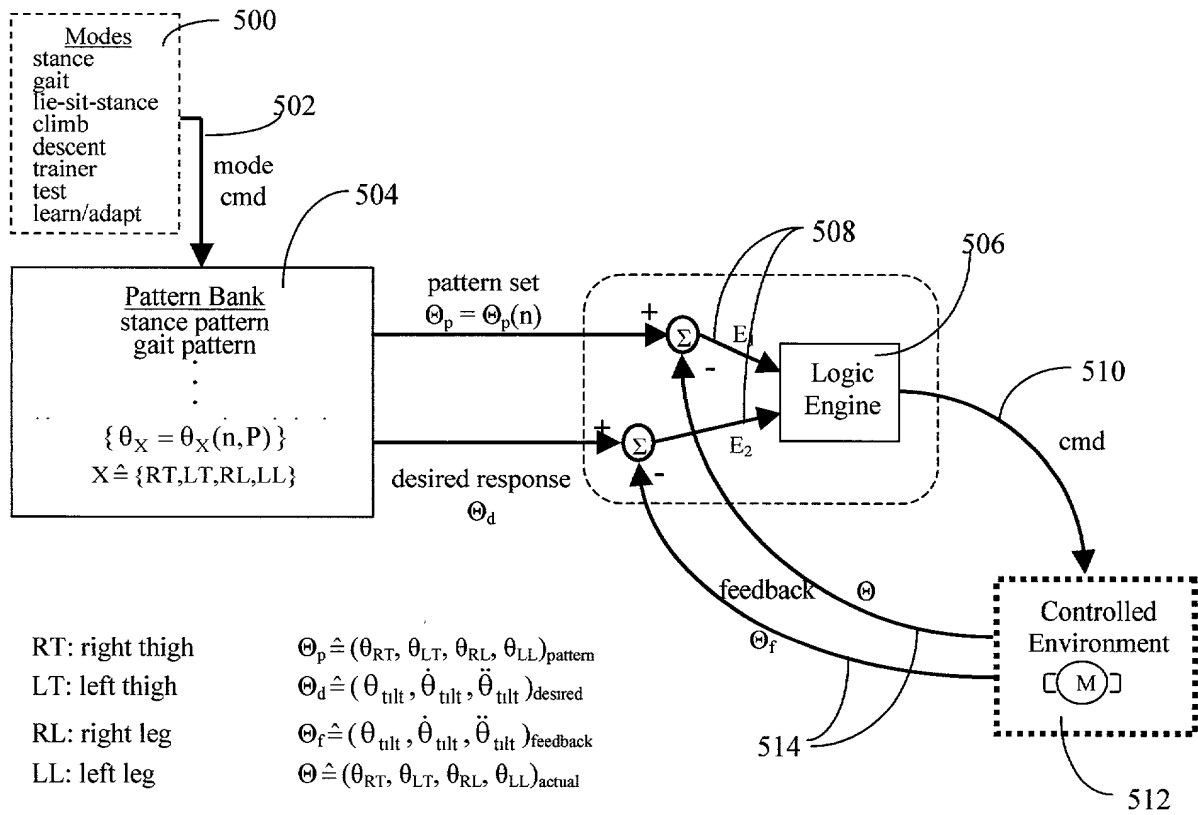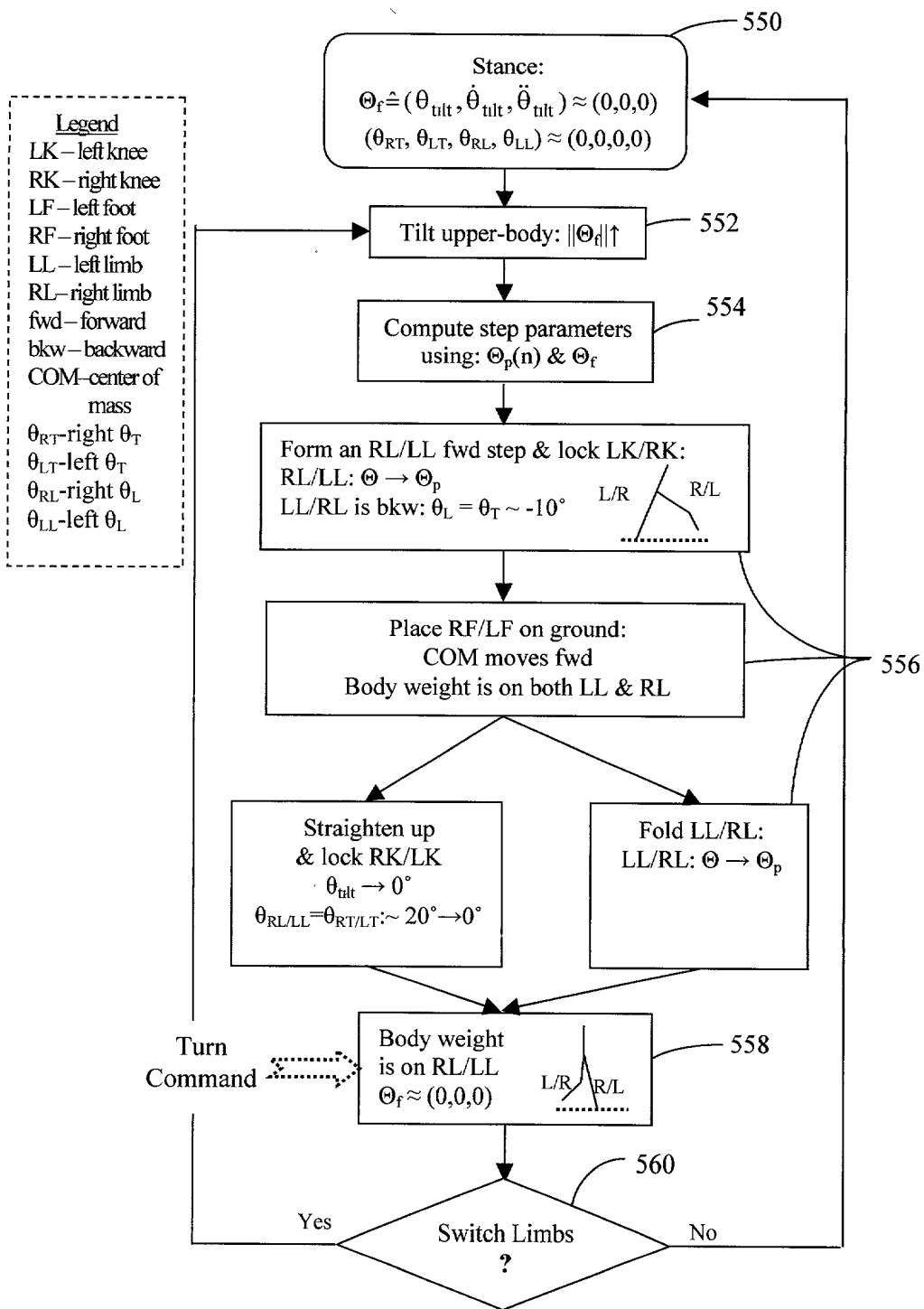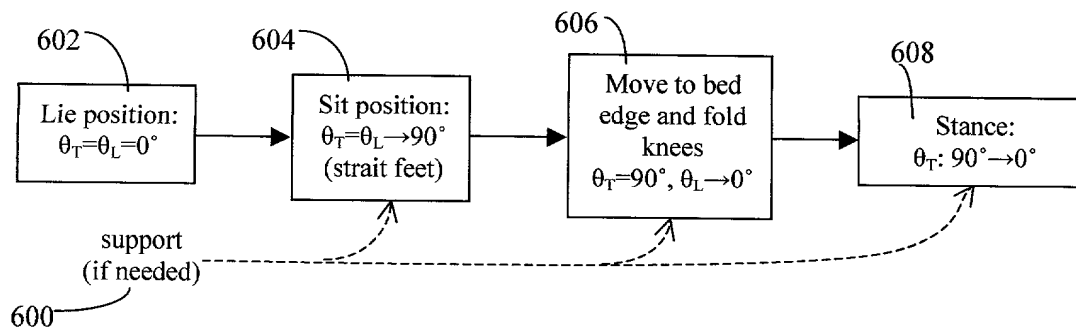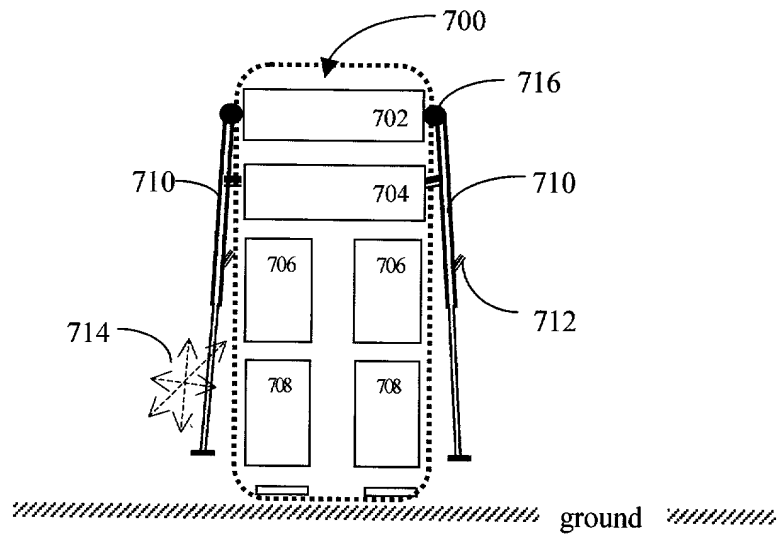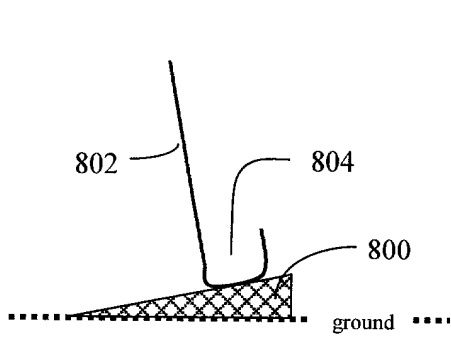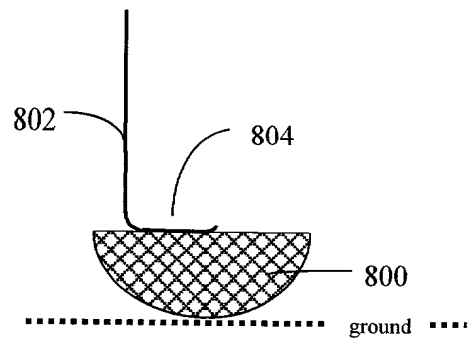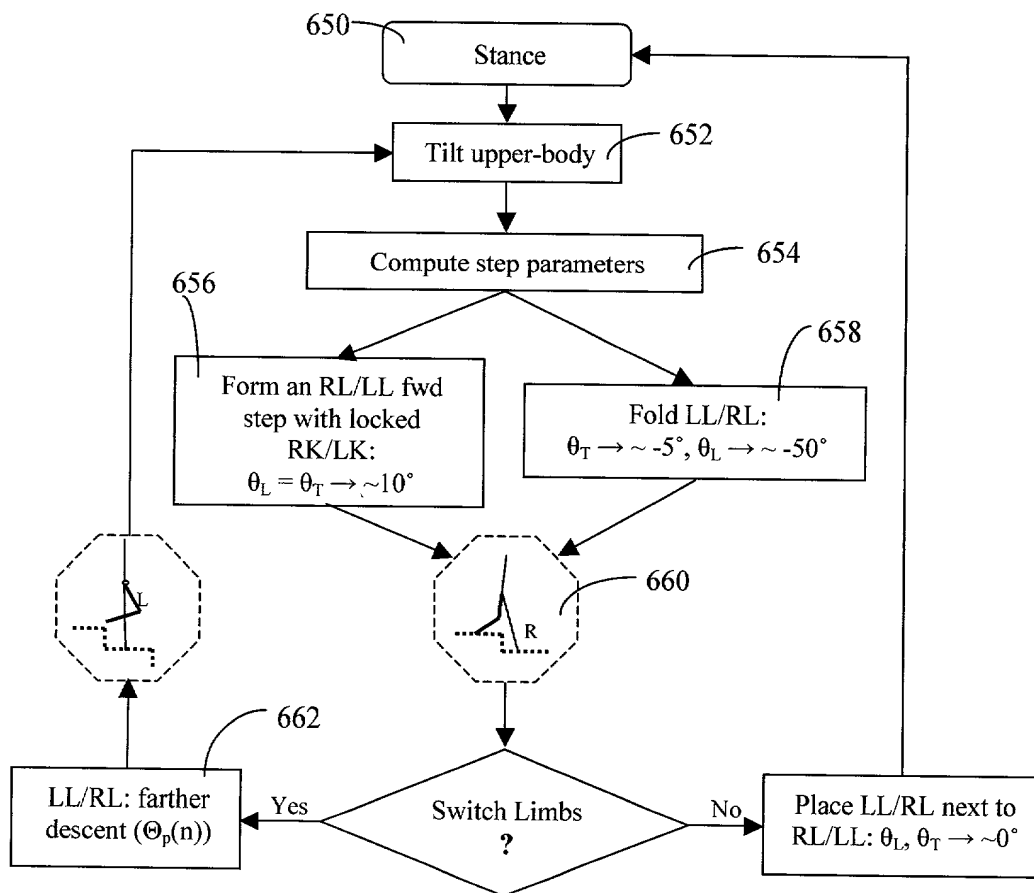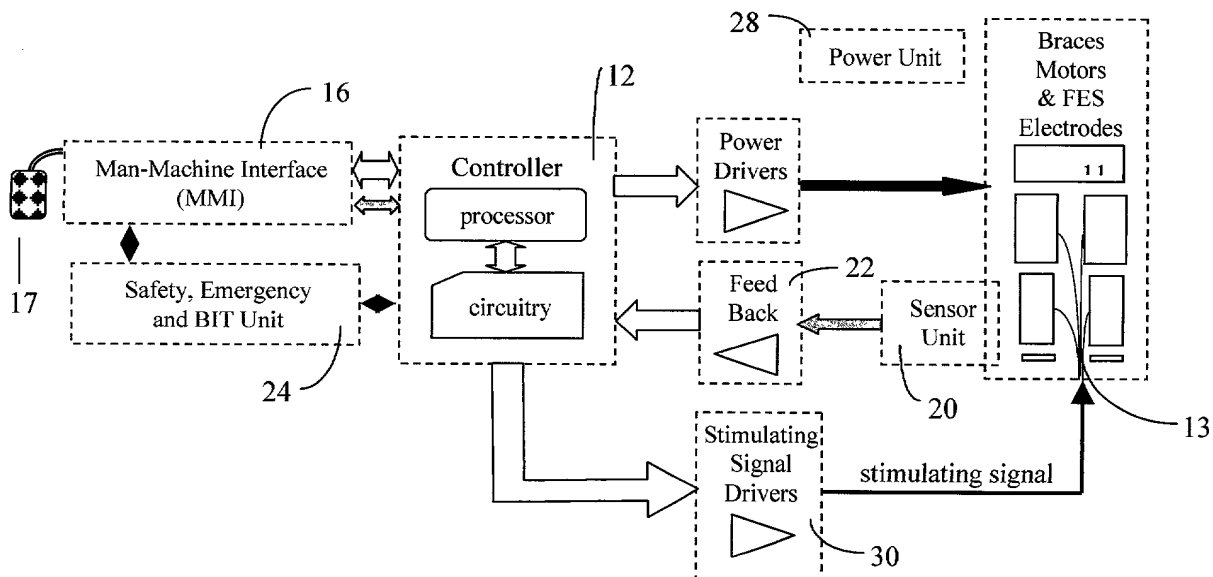
ground

Figure 15

Figure 16a   Figure 16b

Figure 17

Figure 18

Figure 19

Figure 20